BLAST EFFECTS ON LIGHT NONSTRUCTURAL COMPONENTS

A. Altenberg and T. Krauthammer
The Pennsylvania State University, USA

INTRODUCTION

The main focus of this study was the effect of a full blast wave on lightweight nonstructural components, such as window glazing. Both the positive and negative phases of the blast pulse were considered. Previously, structural analysis models considered only the positive phase of the blast load. The structural response is defined by the peak positive and negative values of the pressure, the durations of these pressure phases, and the natural period of the structure. The parameters that govern the shape of the pulse are the distance between the blast source and the structure, and the energy dissipated in the explosion (i.e., equivalent TNT charge weight). A typical blast pressure pulse rises quite abruptly to a peak value, drops to a partial vacuum, and then returns to ambient pressure. Test data showed that, in case of failure, glazing could be either pushed into the building or pulled out of its frame. This could be possible if the relative characteristics of the full pulse, with respect to the dynamic characteristics of the structure, can excite different types of structural responses. That requires a numerical tool to show that under certain conditions the glazing can be pulled out of the structure in the direction opposite to the incoming blast.

APPROACH

Modeling the response of lightweight panels under blast loads involves two fundamental parts: The evaluation of the structural response, and the use of an adequate failure criterion for the assessment of breakage. Further, the evaluation of the response involves two different parts: The behavior of the panel subjected to a dynamic pulse (blast loading), and the blast loading itself.

For the lightweight panel, two window glass sizes were selected for the parametric study. The selected dimensions were common sizes found in the market. Therefore, the possible effect of blast on conventional building glazing was analyzed. Such sizes were 1,397 × 1,448 × 9.63 mm, with an aspect ratio of approximately one, and 1,524 × 2,438 × 6.4 mm, with aspect ratio 0.625. The failure prediction model of Beason and Morgan (1984) was used with the values m=6, and k=4.40E-25 $in.^{10}\,lb.^{-6}$ for the parameters representing the glass flaws. These parameters correspond to in-service glass (approximately after 25 years of service).

Two sizes were selected for the explosive source: 10 Kg, and 100 Kg TNT. Scaled distances were taken in a range from zero to 100 $ft/(lbs)^{1/3}$, representing relatively close and far explosions, respectively. A linear model was chosen to represent the dynamic system, and the stresses in the glass plate.

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **AUG 1996**	2. REPORT TYPE	3. DATES COVERED **00-00-1996 to 00-00-1996**

4. TITLE AND SUBTITLE **Blast Effects on Light Nonstructural Components**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Pennsylvania State University,212 Sackett Bldg,University Park,PA,16802-1408**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM000767. Proceedings of the Twenty-Seventh DoD Explosives Safety Seminar Held in Las Vegas, NV on 22-26 August 1996.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

DYNAMIC ANALYSIS RESPONSE OF THE GLASS PLATE

A linear SDOF system without damping was used to model the response of the glass plates, which followed the approach of Biggs (1964). The equivalent system was selected so that the deflection of the concentrated mass was the same as the deflection at the central point of the glass plate. The boundary conditions were selected fully simply supported.

The values of the peak positive and negative pressures, and duration of the positive and negative phase pulses were taken from Drake et al. (1989). The pulse was modeled linearly, as shown in Figure 1.

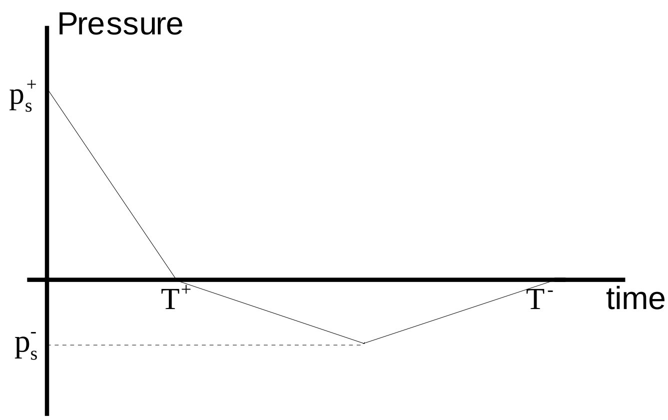

Figure 1: Pulse Shape

Mathematica (Wolfram, 1991) was used for the numerical solution of the following differential equation representing the dynamic response of the plate:

$$K_M\, M\, \ddot{x} + K_R\, K\, x = K_L\, F(t)$$

Where M, is the total mass of the plate, K, is the actual stiffness of the plate, F(t), the actual load-time function, the factors K_M, K_R, K_L were defined by Biggs (1964), and $\ddot{x}$ and x are the acceleration and displacement of the equivalent system respectively. Damping was not considered in this approach.

The general approach presented by Timoshenko and Woinowski-Krieger (1959) was used for the calculation of the stresses in the plate. The model does not consider geometric nonlinearity and shear stresses, and it resulted in the following equations for the peak stresses:

$$(\sigma_x)_{\max} = \frac{6\,M_x}{h^2} \qquad \textit{and} \qquad (\sigma_y)_{\max} = \frac{6\,M_y}{h^2}$$

In which h represents the thickness of the plate. The flexural moments M_x and M_y were calculated at the center of the plate, as a function of the central deflection, w.

A glass failure prediction model developed by Beason and Morgan (1984) was used to compute the failure probability of the plates. The failure probability can be expressed as

$$P_f = 1 - e^{-B}$$

In which B is a function that reflects the risk of failure. The strength of glass depends on the magnitude and duration of the surface tensile stresses in the plate, the surface area of the plate exposed to tensile stress, and the geometries and orientations of the surface flaws. The risk function, B, includes these factors.

Using the solution of the maximum principal stress at the center of the plate was expressed as a function of the displacement at the same location:

$$(\sigma_x)_{max} = \varphi(w)$$

In which φ is a linear function of the displacement at the center of the plate, and $(\sigma_x)_{max}$ is the maximum principal stress at the center of the plate. With the dynamic response of the plate w(t) an equivalent constant stress of the same duration of the structural pulse in the sense given by Beason and Morgan (1984) was calculated.

$$\bar{\sigma}_{td} = \left[\frac{\int_0^{t_{ds}} \sigma(t)^n \, dt}{t_{ds}} \right]^{1/n}$$

In which t_{ds} is the duration of the structural response, $\bar{\sigma}_{td}$ is the equivalent stress and n is 16. In the same fashion (Timoshenko and Woinowski-Krieger, 1959), the maximum principal stress at the center of the plate can be expressed as a function of a constant uniform load that would produce such stress. Therefore, the simplified formulation for rectangular plates proposed by Beason and Morgan(1984) can be used. Such simplified formulation was used for both the positive and negative pulses of the structural response.

APPLICATION AND RESULTS

Traditionally only the positive pulse load has been considered for the response analysis of structures subjected to blast loads. The purpose of this paper is to show that this approach is not valid when considering light elements, such as window glass.

No test data are available for the validation of the cases simulated in this study. However, the effectiveness of this approach can be shown by comparison with results from Blastop (Meyers et al., 1994). The differences between Blastop and the method developed in this study are summarized in

Table 1, and representative for the same glass panels results are compared in Tables 2 and 3. The comparison shows that the present approach can show outward failure (i.e., opposite to the blast direction). This cannot be achieved with Blastop. Otherwise, the data compare well.

Table 1: Comparison Between Blastop and the Present Model.

Item	Blastop	Model used in this study
Geometric considerations	Considers the geometric nonlinear response of the glass plate.	Linear resistance analysis.
Support Conditions	The plate is simply supported with some slide at large deflections.	The plate is simply supported.
Damping	Uses a damping factor of 2%.	Does not consider damping.
Blast Pulse	Does not include the negative phase.	Includes the negative phase.
Failure Criterion	Allowable stress with normal distribution of the properties of glass.	Beason and Morgan (1984)

Table 2: Comparison of Results for an Explosion Source of 100 Kg TNT

STRUCTURE OF ASPECT RATIO ONE						
z [ft/lb$^{1/3}$]	Blastop			Present Model		
	Max. deflection [in.]	Prob. failure inward	Prob. failure outward	Max. deflection [in.]	Prob. failure inward	Prob. failure outward
20	2.88	1.000	NONE	3.80	1.00	NA
30	2.20	1.000		2.87	1.00	NA
40	1.94	1.000		2.25	0.99	NA
50	1.54	0.974		1.92	0.97	NA
60	1.21	0.514		1.62	0.71	0.71
70	1.00	0.175		1.31	0.48	0.48
80	0.94	0.117		1.10	0.32	0.29
90	0.84	0.055		0.99	0.24	0.20
100	0.77	0.031		0.88	0.16	0.12

NA - Not applicable.

Table 3: Comparison of Results for an Explosion Source of 10 Kg TNT

STRUCTURE OF ASPECT RATIO ONE						
z [ft/lb$^{1/3}$]	Blastop			Present Model		
	Max. deflection [in.]	Prob. failure inward	Prob. failure outward	Max. deflection [in.]	Prob. failure inward	Prob. failure outward
20	1.56	0.980	NONE	2.20	0.80	1.00
30	1.13	0.360		1.70	0.64	1.00
40	1.23	0.560		1.40	0.56	0.96
50	0.94	0.120		1.20	0.40	0.90
60	0.82	0.050		1.00	0.26	0.70
70	0.63	0.020		0.85	0.12	0.46
80	0.59	0.012		0.70	0.06	0.32
90	0.54	0.010		0.60	0.04	0.24
100	0.52	0.008		0.55	0.02	0.14

CONCLUSIONS

It can be concluded that, under certain conditions, the negative phase of the blast pulse causes the lightweight panel to be pulled out of its frame. That behavior can be achieved only for relatively small overpressure values, when the partial vacuum increases its relative importance. That could be possible for small charges exploding near the structure, or for large charges detonated further away from it. The behavior of a given panel under a relatively small blast load is totally different from the behavior under a relatively large blast load. In fact, for a given panel, the difference between the maximum displacement in the direction opposite to the blast and that in the blast direction changes with different values of the blast load. Therefore, the relative characteristics of the panel, with respect to the explosion, govern the behavior of the system. It is known from structural dynamics that a representative parameter of that behavior is the ratio between the blast duration and the natural period of the structure (t/T). One may find, for any explosion source and panel size, a t/T range for which the displacement opposite to the blast direction dominates. Unfortunately, such t/T ranges are not constant, even for glass panels of the same characteristics. That is caused by the change of pulse shape for different values of the explosive weight. Therefore, t/T cannot be used to define the general panel response.

REFERENCES

Beason, W.L., Morgan, J.R., "Glass Failure Prediction Model," Journal Structural Engineering, Vol. 110, № 2, February 1984.

Biggs, J.M., "Introduction to Structural Dynamics," McGraw-Hill, Inc., 1964.

Drake, J.L., Twisdale, L.A., Frank, R.A., Dass, W.C., Rochefort, M.A., Walker, R.E., Britt, J.R., Murphy, C.E., Slawson, T.R., and Sues, R.H., "Protective Construction Design Manual," Final Report, ESL-TR-87-57, November 1989.

Meyers, G.E., Baldwin, D., and Mlakar, P., "State of the Art of Blast Resistant Windows," Proceedings of the 26th. Department of Defense Explosive Safety Seminar, Department of Defense Explosive Safety Board, 1994.

Timoshenko, S., Woinowsky-Krieger, S., "Theory of Plates and Shells," McGraw-Hill, 1959.

Wolfram, S., "Mathematica: A System for Doing Mathematics by Computer," 2nd Edition, Addison-Wesley Publishing Company, 1991.